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Selection of an Optical Fiber for the Radiation Environment of the Satellite X-Ray Test Facility.

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by Timothy R. Oldham
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and Development Command
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The pulsed radiation environment of the proposed Satellite X-Ray Test Facility (SXTF) consists of synchronized pulses of low-energy plasma radiation and bremsstrahlung produced by 150-keV electrons. In addition, there is also a low level, steady spray of 1-MeV electrons. In the experiments reported here, pulsed irradiation was performed by using the Harry Diamond Laboratories FX-45 in the bremsstrahlung mode, and the steady state irradiation was performed by using a ^{60}Co source. The

Item 20 (Cont'd)

SXTF fiber has to carry an analog signal during the radiation pulse with negligible distortion due to transient darkening or Cerenkov radiation. Several fibers were tested, and the IVPO fiber was found to be the best because it has very little transient darkening. Cerenkov radiation was effectively removed from all transmitted signals by using narrow optical bandpass filters.

CONTENTS

FIGURES

1. INTRODUCTION

In recent years, fiber optic waveguide has been recognized as an ideal means of communication in electromagnetic pulse (EMP) and system-generated electromagnetic pulse (SGEMP) environments. For this reason, a number of fiber optic signal transmission systems have been built.* The most serious drawback to these systems is that nuclear radiation can severely degrade their performance. The effect of radiation on fiber optical cable has been studied by several investigators.† All these studies have been concerned with recovery of the fiber *after* pulsed radiation or with the response of the fiber to continuous (for example, ^{60}Co) radiation.

In the proposed Satellite X-Ray Test Facility (SXTF), the fiber must transmit an analog signal *during* the radiation pulse without significant degradation from either luminescence (primarily of Cerenkov origin[1]) or transient darkening. In addition, the fiber might be exposed to a low level background radiation that could produce significant permanent darkening over an extended period. For this reason, we measured transient darkening during an x-ray pulse and also permanent darkening in a ^{60}Co environment. The purpose of this work was to select an optical fiber to be used in the radiation environment of the SXTF.

2. TRANSIENT MEASUREMENTS IN SXTF RADIATION ENVIRONMENT

The nominal radiation pulse to which the fiber would be exposed is 5×10^{-4} cal/cm^2 bremsstrahlung from 150-keV electrons. We used the Biggs-Lighthill analytic approximation[2] to calculate the dose in the fiber from this pulse. We assumed a triangular photon spectrum with a cutoff energy of 150 keV incident on a 2-mil (0.0508-mm) tantalum foil to approximate the self-absorption of the bremsstrahlung target. The spectrum transmitted through the tantalum foil was then normalized to 5×10^{-4} cal/cm^2. In figure 1, the shaded area corresponds to the transmitted fluence. We calculated a dose of about 40 rad (Si) for this spectrum and fluence and 25 rad (SiO_2) in the glass fiber. For a thinner tantalum bremsstrahlung target, the dose would be somewhat higher, but it should not be more than about 50 rad (Si) for any realistic foil. For this reason, we selected 50 rad (Si) as the nominal threat level.

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[1] *J. Golob, P. Lyons, and L. Looney, IEEE Trans. Nucl. Sci.*, NS-24 *(1977), 2164.*

[2] *F. Biggs and R. Lighthill, Analytical Approximations for X-Ray Cross Sections II, Sandia Laboratories, Albuquerque, NM, SC-RR-71-0507 (December 1971).*

*See *Selected Bibliography--Fiber Optic Signal Transmission Systems.*

†See *Selected Bibliography--Effect of Radiation on Fiber Optic Cable.*

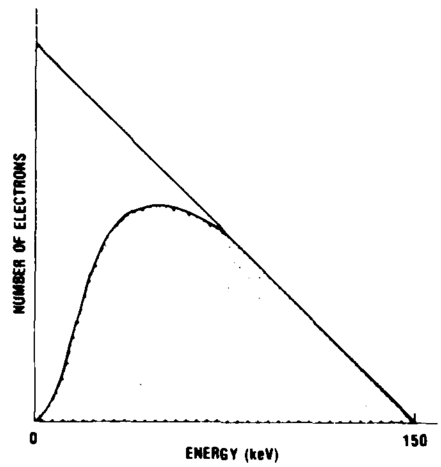

Figure 1. Qualitative bremsstrahlung spectrum.

In the transient radiation experiments, we used the Harry Diamond *Laboratories (HDL) FX-45 as a radiation source.** † *This machine pro*duces an electron beam with an average energy of about 2 MeV, which is incident on a 2-mil tantalum bremsstrahlung target. The exposure of the sample can be varied from a fraction of a roentgen to 1500 or 2000 R. In these experiments, the exposures of the fibers varied from about 25 to 2000 R, the maximum of the machine.

The experimental apparatus is depicted schematically in figure 2. The signal generator drove an infrared laser (wavelength = 860 nm) with a 100-MHz sine wave. The fiber carried the signal into the exposure area and then back to an avalanche detector. For pulses for which we measured darkening, we used an interference filter to eliminate Cerenkov radiation. For pulses for which we measured Cerenkov radiation, we removed the interference filter. For both measurements, we used enough neutral density filter (typically, two pieces of ND 1.0) to keep from overloading the detector.

We tested four kinds of fibers: A, OVPO, the external process; B, IVPO, phosphorous doped internal process; C, germanium doped borosilicate glass; and D, plastic clad silica (PCS). The darkening results are presented in figure 3. The attenuation plotted on the vertical axis is

**Stewart E. Graybill, Ion Physics, Burlington, MA (1968).*
†*Joseph D. Silverstein, Harry Diamond Laboratories (1973).*

the ratio of the minimum sine wave amplitude (during the pulse) to the amplitude before the pulse. Since we were forced to use different lengths of each fiber, we have normalized the results to a standard length of 1 km. The exposure is plotted in roentgens. Clearly, fiber B has the least transient darkening, about 25 dB/km, at 50 R, which is the level of greatest interest.

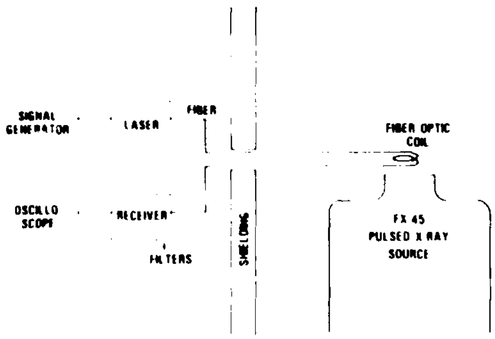

Figure 2. Schematic of experimental apparatus.

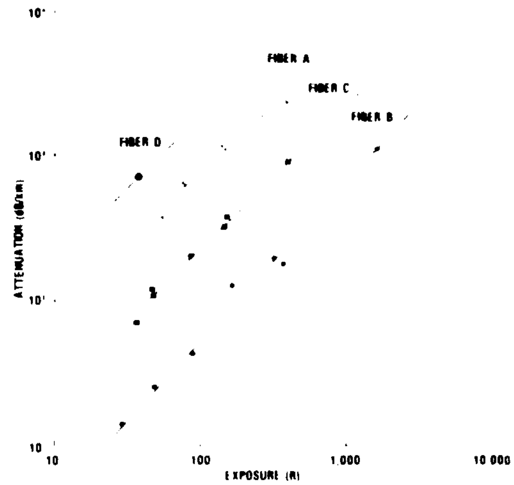

Figure 3. Darkening as function of radiation exposure during pulse.

Figure 4 shows the oscilloscope trace for a darkening shot at an average exposure of about 1600 R for fiber B. In this shot, the attenuation is approximately 1180 dB/km, and there is substantial recovery of the fiber within 1 µs or so. The oscilloscope traces for the 50-R point are presented in figure 5. Since only about 5 m of this fiber was exposed to radiation, the attenuation is difficult to see with the unaided eye. In fact, one cannot easily tell from the oscilloscope trace when the radiation pulse arrived. The timing of the pulse can be seen more clearly from figure 6, which shows the results of a Cerenkov shot at the same exposure conditions as in figure 3. For the data in figure 6, the laser was turned off and the interference filter was removed, but the dose and the timing of the recording oscilloscope were the same as in figure 5. The Cerenkov pulse in figure 6(a) has the same shape as the radiation pulse, and they have essentially the same timing. The height of the Cerenkov pulse is only 10 mV as opposed to the 400-mV modulation of the laser output shown in the calibration trace in figure 6(b). If an interference filter were included (as it is on darkening shots), the Cerenkov radiation would be reduced so much that it could not be detected. In fact, there is no sign of a Cerenkov pulse in figure 5. Since Cerenkov radiation seems not to be a problem with fiber B (or with any other fiber, for that matter), we have generally ignored it to concentrate on transient darkening.

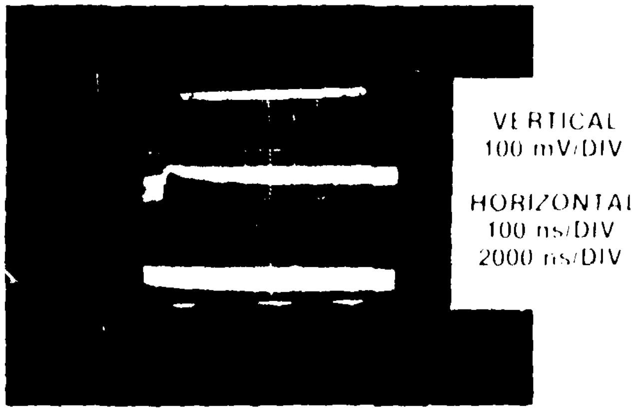

Figure 4. Fiber R darkening shot,
exposure 1e15 R.

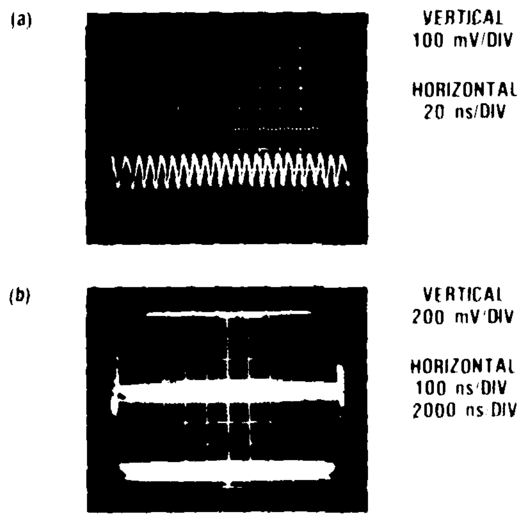

Figure 5. Fiber [illegible] darkening shot,
exposure 4e[illegible] R.

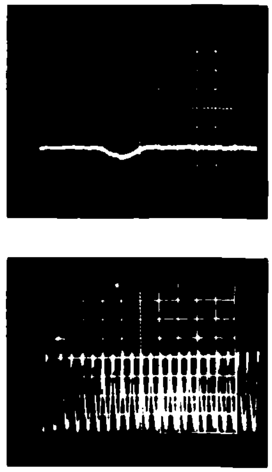

Figure 6. Fiber B Cerenkov shot,
exposure = 50 R.

The results of exposing fiber A to 395 R are shown in figure 7. Only about 3 m of fiber was exposed to radiation. Even though the dose is lower than for figure 4, there is obviously more darkening and slower recovery than for fiber B.

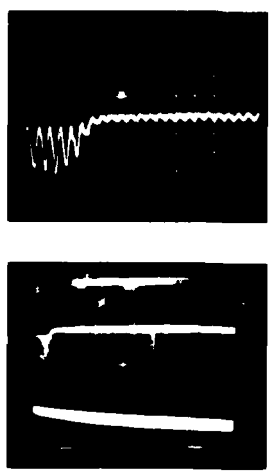

Figure 7. Fiber A darkening shot,
exposure = 395 R.

Figure 8 presents the results of a darkening shot on fiber D. This figure shows the effects of strong radiation darkening. Even though the exposure was less than 40 R, the attenuation was nearly 700 dB/km. We exposed this fiber only once because its performance was inferior to that of the other fibers and well below that required.

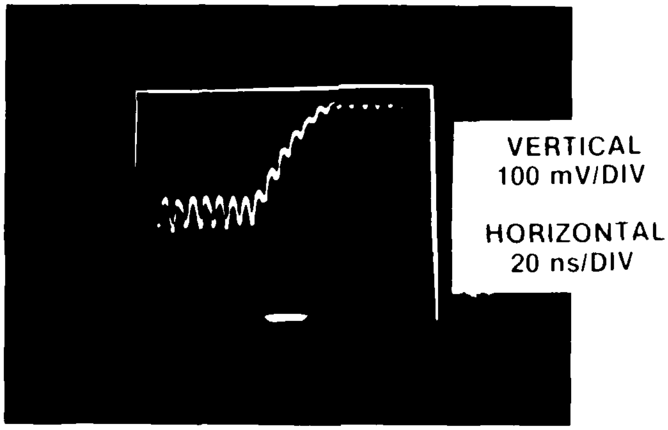

Figure 8. Fiber D darkening shot, exposure = 38 R.

3. STEADY STATE MEASUREMENTS

The SXTF fiber must withstand not only transient radiation, but also the flux from a number of electron guns spraying the satellites with 1-MeV electrons with a flux of 1 nA/cm^2 for extended periods. For this reason, we performed a series of permanent darkening measurements on fiber B.

These measurements were performed by using HDL's ^{60}Co facility as the radiation source. There are actually two ^{60}Co sources available; the small source provided an exposure rate of 52 R/s, and the large source supplied 779 R/s. We exposed a 20-m length of fiber in each source and recorded the attenuation as a function of time (which is to say, exposure). The results are presented in figure 9; the horizontal axis is exposure in roentgens and the vertical axis is in decibels per meter. The signal was attenuated enough that the points above 15,000 R or so cannot be read accurately. In other words, the fiber was completely darkened after about 6 min in the small source or 25 s in the large source. After the samples were removed from the radiation sources, we observed slight recovery for the first hour, but no measurable recovery thereafter. The degree of recovery is obvious from the

four traces in figure 10: (a) the signal before irradiation, (b) the signal immediately after irradiation, (c) after 1 hr of recovery, and (d) after approximately 18 hr of recovery. All the traces in figure 10 are for the sample exposed in the small source. The conclusion from this experiment is that the fibers darken completely after 15,000 to 20,000 R (13 to 17 krad [SiO_2]), and they stay darkened after the radiation is turned off.

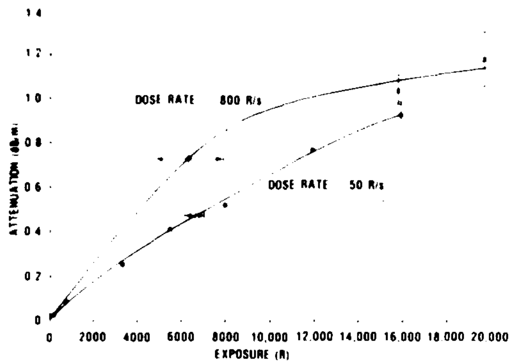

Figure 9. Results of ^{60}Co irradiation of fiber B.

We used the computer code ZEBRA-1 to calculate the dose rate in the fiber for a flux of 1 nA/cm^2 of 1-MeV electrons.[3] The answer was approximately 170 rad (SiO_2)/s for bare fiber. That is, the electron spray would produce complete darkening in less than 100 s. The exposure time would be much longer than 100 s, so the fiber would somehow have to be protected from the electron spray, probably by some kind of shielding.

[3] *L. D. Buxton, The Electron Transport Computer Code ZEBRA-1, Harry Diamond Laboratories HDL-TR-1536 (1971).*

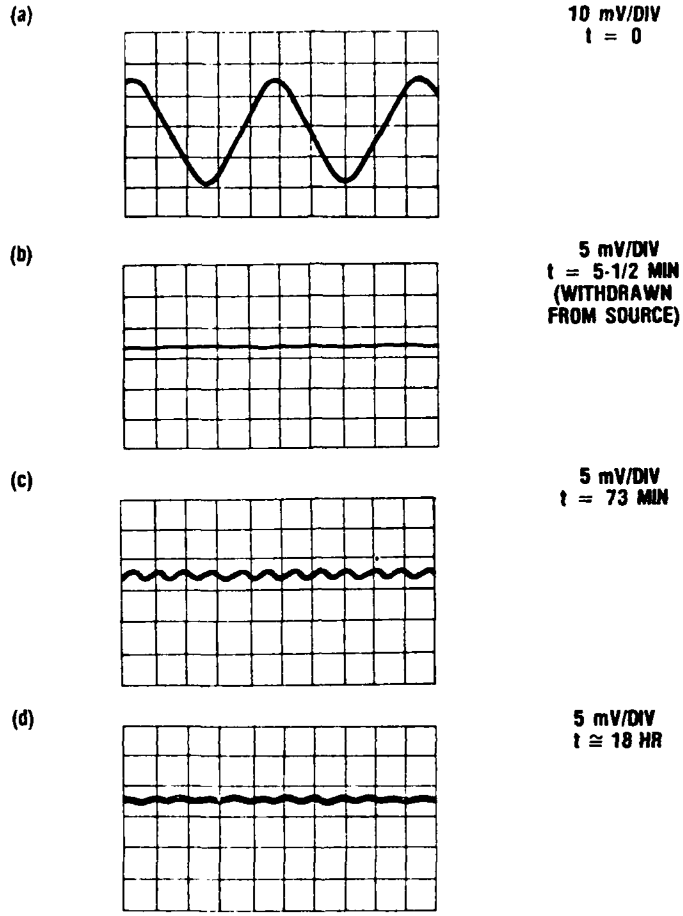

Figure 10. Experimental data for permanent darkening from ^{60}Co irradiation of fiber B.

4. CONCLUSIONS

The conclusions for all the pulsed radiation measurements are that Cerenkov radiation will never be a problem and that fiber B is resistant enough against transient darkening to be used in the SXTF. The lengths of fiber exposed in the SXTF would be at most a few tens of meters, and the exposure would be at most 50 R. For these conditions, the attenuation will be much less than 1 dB during the pulse. Since fiber B is good enough at room temperature for the SXTF application, we stopped looking for a better fiber. During the bremsstrahlung pulse, Cerenkov radiation is not a problem at all for any fiber, and transient darkening is not a problem for fiber B as long as it is protected from the electron spray. It is for this reason that fiber B was selected, although it will have to be protected from the steady state electron spray.

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